Hence $\omega = \frac{4 g W' a}{W k^2}$ in radians per second.

Hence number of revolutions per second $= \frac{2 g W' a}{\pi W k^2}$

Substituting the numbers given in the question, we have for the answer—

$$\frac{2 \times 981{\cdot}4 \times 2250 \times 6}{3{\cdot}1416 \times 1800 \times 16}$$

$$= 293 \text{ revolutions per second.}$$

University, Glasgow D. M'FARLANE

The Sounds of the String Organ

MR. BAILLIE HAMILTON'S invention of a conjoined string and reed which is now being carried out in a musical instrument to be called the string organ, has caused a marked interest both in its musical and in its scientific aspects. My attention was attracted to it strongly, for one reason, that it promised to add a new member to the family of keyboard instruments, and for another reason, that the study of its possibilities and practical working showed conditions so close in analogy to those of the organ-pipe as viewed under the theory advanced by me in NATURE, that the corroborative evidence thus furnished might with truth be called palpable. By the last word I refer to the visible displacement and travelling of the node, which can be affected at will in obedience to changes in the relative conditions of reed and string. I find that "tension" on the string is equivalent to "scale" in organ-pipes. To give high tension to a string is in effect the same as to use a narrow scale of pipe; thus, keeping the reed-force constant, we may respectively, by giving higher tension to the string, or by using a narrower pipe, drive the node higher, and conversely, slackening tension or using a wider scale of pipe, we may displace the node to a lower position. In the conjoined reed and string we can see this change taking place, order how it shall take place, and may clip the nodal point with our fingers without disturbance of the continuity of vibrations. The process is visible, the result tangible.

The estimate Lord Rayleigh * has given of the instrument as "modified reed" is undoubtedly right, yet it can scarcely be said that the opposition estimate is undoubtedly wrong. An orthodox organ is a pipe-instrument, and also is a wind-instrument, yet in acoustical relations the pipe is out of theoretical conformity, is a modified pipe; the air-reed likewise, according to the kind of pipe it is allied with, is a modified reed, and similarly in this novel organ the string and reed modify each other; sever the union, and the manifestations of the two independent forces will be wholly different. Specifically it is a wind-instrument, and I cannot but think we should admit it to be both "modified reed" and "modified string;" they work together as a system, each contributing its own character, and each in degree determining, through compromise and affinity, the issue of the union. Strongly impressed with this belief, my explanations will consequently differ from those generally current concerning this ingenious combination.

Lord Rayleigh, in explanation of his estimate, says, "the intermittent stream of air, which does not take its motion from the reed, gives rise to a highly compound musical note." Either I do not understand this affirmation, or I misunderstand it; I have always considered the intermittence of the stream to be the result of the reed's motion. And further on, another sentence to strengthen his distinction: "The fact that the *pitch* of the system is mainly dependent upon the string seems to have distracted attention from the important part played by the stream of air, and yet it is obvious that wind cannot be forced through such a passage as the reed affords without the production of sound." Speaking, not without experience in varieties of free reeds, I cannot recall a single instance of the wind forced through the passage afforded by the reed producing anything like a musical sound. Our views probably differ in expression and in interpretation more than in perception.

With some temerity I think I may say that the working of the free reed is not fairly estimated by scientific observers. It is generally supposed that the *pressure* of the wind originates the vibration of the reed in instruments, whereas the fact is that the free reed may be so set that although perfectly free to pass, as may be seen on holding it up to the light, perfectly free to sound, as may be proved by percussion, yet, placed within the instrument, it will be dumb to all pressure of the wind. The essential condition for speech is for the reed to be so set that a sufficient amount of air shall with velocity pass the sides and through the mortice of the reed equal to causing a suction on the under side of the reed; then only will the reed proceed on its course, and the check given to the stream when the reed reaches the level of the block intensifies the suction, the development whereof progresses until the back-lash or return of the reed creates a stronger partial vacuum with a promptness of power effectual for establishing the condition of vibration. There are peculiarities, too, in the process of the suction, not lightly to be passed over by the scientific observer. The true test of action is the degree of quickness in speech. The most prompt articulation is that in which the process of suction is most gradual; this is not paradoxical, though it may seem so. If a large amount of wind is allowed to pass, the action will be sudden, yet, notwithstanding, the speech, comparatively estimated, will be slow. The suction should first attack the tip of the reed and gradually draw upon the stem. If you allow passage to the wind near the root of the reed, or if you hollow or arch the stem, permitting wind more freely to pass the middle of the reed, it is inevitably at the sacrifice of quickness of speech, and nothing is more fatal than allowing extra opening for a rush of air between the tip of the reed and the frame, for you thereby impair the perfectness of the suction at its most vital point.

In the case of a reed and string conjoined, the string is a weight to be moved; the force of wind will effect the displacement if the string has held the reed in position to allow passage of wind; and when the equilibrium of the string has been in the least degree disturbed, the return motion becomes a source of additional impetus, inducing the reed to follow by reciprocation; yet even here we do not escape the demand for suction; the value for this purpose of a tube or a channel beyond the reed is as evident as in the harmonium. The difference between the modern harmonium and the old seraphine is, that the former has pipes or channels to every reed, the latter had its reeds placed over apertures in plain boards; the reed conjoined to a string when so placed over a simple aperture will sound as would the reed in the old seraphine, but generally with the exhibition of the same defect, slowness of speech. Select an instance of such a string and reed so sluggish that the attainment of speech to the semblance of a musical note is a trial of patience; then add a tube of suitable character, and, in comparison of condition, the promptitude of response and power of tone will give certain evidence of its value, for here, as in all musical instruments, the function of the tube is to aid and to develop more strongly the force of suction. The suction I mean is that which is caused by the issue of a current of compressed or condensed air into the atmosphere.

A very curious problem is afforded in the peculiar quality of tone given by the new mechanical action of "reed-and-string" working linked together, and I have not heard, from any of the numerous thinkers and observers who have commented upon it, a satisfactory solution. Lord Rayleigh truly states, "it is certain that the note actually heard is compound," and also that "the peculiar character of the string, that its notes form a harmonic scale, does not come into play."

What is it, then, that we hear, and how comes this highly compound musical note into being? Let me offer this solution, if only as a suggestion. It is generally agreed that "there is a great deal of octave in the tone," sometimes the fifth, and frequently and most strikingly a beautiful major tenth, so clear that it seems to sing away by itself as if in independent existence; this, whilst it is certain that the string is not vibrating in forms either of the octave, fifth, or tenth or of any other of the accessory tones so often present to the ear. Rightly to apprehend the action of strings in musical instruments, it is, I think, desirable to regard every string as a tuning-fork acting upon the sound-board through the bridge, which, thus considered, is its stem for the communication of its vibrations. The intensity of sound from a tuning-fork or from a string depends not alone on amplitude of movement, but on pressure, the amount of such pressure being mainly determined in the case of the string by the angle the string makes in its strain upon the bridge under the particular tension to which it is subjected. A tuning-fork sounds loudly or softly, according as its stem is pressed strongly or lightly by the hand upon the sound-board. A string deflected right and left delivers each way its pulse through the bridge to the sound-board; a free reed, moving forward and backward, gives an effective impulse as musical vibration one way only—in the back-lash, or return; consequently, in this matter of conjoined reed and string, it appears to me we have always two fundamentals—two tones

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* See NATURE, vol. xi. p. 308.

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having distinct powers, and either of which may take the position of root or prime; these coexistent tones, whatever the previous independent ratio of string and reed as regards pitch, will always, when thus yoked together, be one an octave higher than the other. Singularly, too, it is not necessary that the lower of these fundamentals should be the pitch-note to the ear; its apparent character may be that of a sub-tone. Generally, the higher fundamental is the leading tone, and for this reason, that the predominance of one or of the other may be determined by character and by condition. In the reed, amplitude of excursion is the measure of its attainment of strength. In the string, tension is more effectual for power than amplitude is. String-tone thus gains by limitation of excursions of the string, whilst at the same time reed-tone is at a disadvantage from the restriction imposed by tension on the play of the reed. Contrariwise with a lighter string, power may be allotted to the reed, also by tubes, by partial occlusion of orifice, by coverings or shadings, the reed-tone can be modified in a variety of degrees; it may lead in trumpet-like vigour, or be heard only in quiet undertone accompanying the higher sound.

These two notes are rigorously exact in relative pitch, and when both have intensity, although different in kind, they produce other tones, as in the stop of the organ called the "Great Quint," the tone of one pipe added to another that produces a tone a fifth higher, gives rise to a third tone an octave lower, but never perfectly, except on the same conditions, exactness of pitch and intensity, with, as a rule, the higher note voiced the strongest. The reed and string necessarily, if preceding propositions are true, being in relation an octave apart, give rise to summation tones, first to the fifth, and these again to octave, tenth, and the rest in due order, but differing in intensity. In harmonic scale those possible would be octave, twelfth, super-octave, seventeenth, &c., and so here, if reckoned from the lowest tone as the root; but summation tones seem to require for their perfect production the same conditions as named above for difference tones; so that relatively the oc ave becomes by its voicing the leading tone, it fixes the pitch for the series in reference to itself, and thus the ear has cognisance of the tenth, not of the seventeenth. This major tenth to the tonic, so unmistakeable that it could not be gainsaid, was always a puzzle viewed as harmonic. Why it was so clear will readily be perceived when calculated as summation twice fulfilled.

The general supposition is, that because it is a string that is in action with the reed, therefore a stringy tone is in consequence obtained, the proof being that a stringy tone is actually heard. On the contrary, the true action of the string, whence arises the peculiarity of violin or violoncello, does not take place. What then? In a curious way effects are gained which naturally simulate the quality. By stringy quality musicians mean the tone of the bowed string. Amateurs talk eloquently in their way of the string-tone and its beautiful purity, of the reed-tone and its abominations, not heeding that the best judges of quality in sound class the stringy quality as the nearest allied to reed quality. Hence, organ-builders regard all the stops which best imitate the viola tribe, the geigens and gambas, as decidedly reedy in character, otherwise they would be poor representatves. The violoncello so characteristic in tone has always its introductory harmonics; these are sharp to the fundamental tone in which they merge, even as, I have shown in a former paper, the harmonics of the gamba organ-pipe are. Octaves of a free-string are always sharp to the note of the whole string. Then we have also the roughness, the grip, and bite of the bow. The sharpness is minute, yet sufficiently potent to give definite character. The ear is as easily deceived as the eye—the imitation may pass for the real. If we consider what is the effect on the ear of this sharpness, which does not reach the region of beats, we shall find it to be a breezy effect; in the delicate "voix celestes" of a fine organ when finished by true artists, we have it displayed—just a freshening touch of sharpness, and no more. From a breeze to a rough wind is only gradation of similarity. Return now to the combination of reed and string: the effect as of a stringy quality is gained by the breeziness of the outward stream of air distinctly heard, by the roughness of the abrupt closing and opening of passage to a highly-excited reed, by the tendency of a highly resilient reed to a more rapid pace, curbed though it inevitably is to the pace possible to the string it is paired with, thus adding an element of roughness to the sound-board, and in completeness of likeness there are the summation-tones mimicking those harmonics which are present in the fulness of the violoncello tone.

To assure those who would doubtfully accept the above interpretation, let me take an illustration of a practical nature as a verification. Why is it possible to make in a harmonium from free reeds alone a good imitation of violoncello quality? Because an analogous procedure can be adopted. This is the analysis of how it is done. Reeds of "eight-feet tone" of a firm character, rather slow in speech in consequence, but coming into play at a bound without hesitation; then in combination reeds of "sixteen-feet tone," these reeds finely curved, elastic, sensitive, quivering to a breath, their tone comes on at first as a breeze, it is sharp in a minute degree, but as the reeds gain power by amplitude, they flatten in pitch, as is the nature of bass reeds; ascending the scale, a small reed giving the twelfth may be added with advantage. In summary this is what we have: reeds relatively sharp to each other, the roughness, the breezy effect, and the accompanying harmonic offspring, together making the mimaphonic violoncello. Organ-pipe, violoncello, harmonium, and string-organ thus show a family likeness and give countenance to the interpretation.

The beauty of Mr. Hamilton's invention is that it is not limited to string-tone, that by giving predominance of power to either agent, reed or string, through long ranges of variation, many classes of tone as distinct as diapason, horn, flute, trumpet, and others can be satisfactorily imitated, and if its present promises of success are fulfilled, the name of string-organ by which it will be known will be amply justified.

HERMANN SMITH

P.S.—Mathematicians decide that the problem of the instrument is that of a loaded string. This appears to me a one-sided view, taken under limited experiments. Practically, some details of their conclusions are not corroborated; there are several elements entering into the composition not heeded, and a wider experience would show that the problem is equally that of a loaded reed. Here is an instance. I have in action a reed with pin attached; it sounds C sharp; and a string which, independently sounding, gives the F below. These, when conjoined, produce the G between. The note of the string is thus *raised* a whole tone; consequently the weight of the oscillating string is a load on the reed.—H. S.

The Law of Muscular Exhaustion and Restoration

YOUR issue of Jan. 28 is just received, containing a paper (vol. xi. p. 256) by Prof. Frank E. Nipher, wherein he condemns as "entirely unreliable" his first series of experiments on the subject of the exhaustion of the muscles of the arm by mechanical work. A like condemnation he pronounces in the February number of the *American Journal of Science.*

All the experiments in question, new as well as older, having been made at this laboratory, I beg leave to correct the above statements of Prof. Nipher. His new experiments are not so radically different from the old ones; on the contrary, both series demonstrate exactly the same general *law*. The true law is, as Prof. Jevons in his first communication to NATURE already felt it, *logarithmic.* So indeed vary most of the vital processes, because *molecularly* they are comparable to the vibrations of a pendulum in a resisting medium. (See Fechner, Exner, Wundt, Delboef, and others.) That the law has so long been overlooked, so far as muscular action is concerned, is probably due to the fact that the progressive restoration of the muscular tissue disturbs the function for small weights, while structural derangements (evidenced by *pain*) cause a like perturbation for higher values of the weight.

If we consider a system of muscles independent of continued circulation (no restoration) and keep the burden w (kgr.) low enough to cause no pain, then the *time* n (in seconds) during which the statical work can be sustained, or the *number of times* n, that the same *cycle* of motions can be performed until exhaustion takes place, I have found to be—

$$\left.\begin{aligned} n &= \frac{A}{B^w} \\ \text{or} \qquad \log n &= a - b\,w \end{aligned}\right\} \qquad (1)$$

where $\log A = a$; $\log B = b$.

In the five series at hand the following are the values of the constants:—

	a	b
I.—*Statical Work.*		
1. Prof. Jevons, Series III., holding weight ...	2·433	0·1450
II.—*Dynamical Work.*		
2. Prof. Jevons, Series II., pulley and cord ...	1·968	0·0476

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